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Darren Wiese and Phillip Box

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Maritime Platforms Division
Aeronautical and Maritime Research Laboratory

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ABSTRACT

The DIGISTAR III data recorder is a rugged stand alone transient data recorder designed for the recording of parameters associated with detonating explosives. Its characteristics are described, the difficiencies in their performance and modifications to overcome them are explained.

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Executive Summary

The DIGISTAR III recorders were purchased by Maritime Platforms Division (MPD) in the early 1990s to provide a digital recording capability for transient events leading up to the Ship Survivability Enhancement Program (SSEP) on the decommissioned HMAS Derwent. They have become MPD's major capability in recording thousands of data records from explosive events. Modifications to the DIGISTAR recorders and the development of instrumentation methodologies have made them extremely reliable and versatile.

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Phillip has conducted evaluations of explosives and the effects of explosives on platforms, structures and components, including the measurement of shock and blast parameters from detonations in air and underwater for over 19 years.
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Darren graduated from Western Metropolitan College of TAFE with an Associate Diploma of Business (Computer Programming). Since joining AMRL in 1982 he has been involved in explosives research as an explosives firing officer and with instrumenting explosives experiments. He has developed software packages for the analysis of blast parameters for air and underwater detonations. More recently Darren manages the transient data acquisition capability within MPD.

Contents

1. Introduction

The recording of explosive blast parameters requires specialised instrumentation. One instrument designed specifically for this purpose is the DIGItal STand Alone Recorder (DIGISTAR). The DIGISTAR:

1- can acquire data at a sufficient rate to characterise blast parameters;

2- is capable of connecting directly to different transducer types;

3- is rugged enough to itself be subject to some blast loading; and

4- can reliably trigger and record data.

It is rare that an instrument combining all of the above characteristics can be bought at a sufficiently low cost and allow many channels of data to be resolved. This report describes the DIGISTAR recorders and details the improvements implemented in Maritime Platforms Division (MPD) ensuring the units are very reliable, adapt easily to varying instrumentation demands and maintenance requirements are minimised.

2. Maritime Platforms Division's Requirement

The units were originally purchased to support the Ship Survivability Enhancement Program (SSEP). This program included a series of experiments conducted on ex-HMAS Derwent. The requirements were for different types of transducers to be incorporated in an instrumentation system that could be in close proximity to a violent event and required a minimum of additional hardware and cabling and that could be deployed quickly as the time available for the experiments was very short. The DIGISTARS seemed to fit these requirements. Prior to the purchase of the DIGISTAR recorders, MPD relied heavily on instrumentation tape recorders and a small number of digital oscilloscopes or transient recorders. This instrumentation did not meet the requirements of the SSEP. To use the existing instrumentation the appropriate signal conditioners or amplifiers for each transducer type would have to be deployed and the recording instrumentation would have to be isolated from shock and blast loading. Cables would have been deployed from each transducer location to a central instrumentation site. This system of instrumentation was considered to be unviable for the experiments proposed for ex HMAS Derwent.

3. DIGISTAR Description

The DIGISTAR recorders are rugged self-contained single channel, digital recording units designed for autonomous operation in harsh environments. They are designed for recording single-shot events such as measuring parameters of explosive events. Each unit provides excitation for the transducer, amplification of the transducer signal, analogue to digital conversion, digital storage memory for the data, a sophisticated triggering system and a communications system for control and data transfer. They are designed to operate in harsh environments and as such have no internal moving parts or switches, are constructed using heavy circuit boards and housed in stiffened aluminium cases.

3.1 Transducer Types

The units accommodate most types of transducers without the need for additional power supplies or signal conditioners. The units can provide variable amplitude DC excitation for piezo-resistive or strain gauge type transducers and also provide a constant current excitation for Integrated Circuit Piezo-electric (ICP) transducers. This current is not adjustable and is set at manufacture for 8 mA. An option for the units when purchased was for the capability to also accept charge mode piezo-electric transducers. This option was not taken with units bought for Maritime Platforms Division.

3.2 Data Memory and Data Sample Rates

The units provide a variable segmented memory in which the number of segments, size of segments and the data sampling rate for each segment can be programmed. The memory can be distributed in 2 to 8 segments. The first segment is always the 'pre-trigger segment' being data recorded before the trigger signal is received. The size of this segment is simply the remaining memory after the size of the other segments has been programmed. Segmentation allows complex acquisition for signals where the sampling rate required might vary. An example would be the recording of underwater pressures from an explosive detonation. A fast sampling rate may be required to record the detail of the initial shock front, then a slower sampling rate to preserve the available memory and then a fast sampling rate to obtain detail of the bubble pulse. The fastest sampling rate available is 5 million samples per second. Sampling rates as slow as 1000 samples per second are available. Any combination of sampling rate and segment size is possible.

The units purchased by MPD have capacity for 4 million samples (actually 4,194,304). Each sample occupies two bytes of data, so in terms of computer data storage 8 Megabytes is required for the storage of the entire data sampled from each unit. Fortunately the entire data memory does not necessarily need to be transferred to the computer. The software allows the selection of the relevant portion of data to be transferred to the computer.

3.3 Resolution

The DIGISTAR recorders use a 12 bit analogue to digital converter giving a resolution of 1 in 2^{12} or 1 in 4096 of the input range programmed. When sampling rates of one million samples per second or slower are used the resolution improves to 1 in 2^{16} or 1 in 65536 of the input range. This is accomplished by acquiring the data and converting it to digital data using the fastest sampling rate, 5 million samples per second at all times and applying a digital filter which effectively averages the data sampled at the higher rates. The digital filter is a finite impulse response digital decimating filter.

3.4 Triggering

In use the DIGISTAR recorders are set into the record mode, in which they acquire data and store it in memory. On receipt of the appropriate "trigger" signal the units stop acquiring data. The amount of data stored before and after the trigger signal is programmable.

The trigger signal can be of two types: an external trigger which is a signal applied to the connector specifically for this purpose; or an internal trigger which monitors the signal being acquired and determines when this signal exceeds a programmable level. Various settings can be used for the internal filter to assist in the elimination of false triggering because of spurious signals such as electronic noise. MPD routinely use the external trigger giving more reliable triggering and additionally if the external signal correlates to an event trigger, time separations can be determined. Often the units are triggered on a signal coincident with the initiation of explosives.

3.5 Control and Data Transfer

The units are controlled by a personal computer (PC) running proprietary software in a Windows environment. The units are 'daisy-chained' or networked together allowing a number of units to be controlled from one PC at the one time. The communication process makes use of the RS-232 interface on the PC. The software uses this interface in a novel way over a 2 wire connection and can achieve communication rates of 230,000 bits per second with an accelerator card inserted and 115,000 bits per second without any extra circuitry. Although faster than conventional RS-232, the time taken to transfer data from the DIGISTARS to the computer is considerable and if "extracting" the DIGISTAR'S full memory of 4 million samples it can take as long as 20 minutes for each recorder. If communicating over considerable distances, greater than 5 m, a line driver is used to amplify the communications signal. Modern PCs (i.e. Pentiums) require the use of a line driver because they cannot provide the required current to communicate effectively.

3.6 Connections

Connections on the front panel of each unit provide for transducer connections, network connection, trigger connection and external power connection. BNC connectors are used for network, trigger and power connection. The BNC connections between each unit can be joined in parallel using conventional BNC connectors. The miniature 'Lemo' connector was used for the transducer connection. This has since been modified, see Section 5.4. The external power required is 12 Volt DC.

3.7 Power Supply

Each unit contains five internal 1.2 Volt Nickel Cadmium (NiCad) batteries. 12 Volt DC power supplies or batteries provide external power. The units can operate on the internal batteries alone but only for a limited time. This time is unpredictable as it depends on the batteries state of charge.

3.8 Other Features

The proprietary software was written with "user friendly" features, taking full advantage of the windows environment and limiting the amount of manual calculations required for instrumentation settings.

3.8.1 Amplifier Gain Setting

One aspect of measuring transient signals is setting the appropriate amplifier gains for the expected input signal range. The DIGISTAR software allows the user to enter the sensitivity of the transducers, in mV per engineering units, and then the expected signal range in these engineering units. The software calculates the required amplifier gains to best accommodate the expected signal.

3.8.2 Oscilloscope Mode

The units are designed for the measurement of one-off events, particularly transients involving explosives. These events cannot be repeated easily. It is good practice to test each and every aspect of the instrumentation before each explosive event. One test routinely conducted is a function test of the transducer through the cabling and recording unit to be used for the event. For blast pressure gauges this is simply tapping the transducer to produce a signal. The DIGISTAR software provides a mode for doing these tests. It is called 'scope mode'. In this mode the signal at the recording unit is displayed on the computer screen in the same manner as a signal on an oscilloscope screen without any signal being permanently stored in memory. This mode is used extensively in pre-event testing.

3.8.3 Signal zero balance

The software allows for the balancing of the signal. This amounts to a compensating voltage of equal amplitude but opposite polarity to any 'offset' in the signal from the transducer. The units are battery powered and provide the appropriate excitation for the transducers. To ensure that energy is not wasted by having the transducers excited at all times, the excitation is only turned on when the DIGISTAR is programmed ready for data recording. To allow for transducer settling time after they are initially energised a time is entered in the software after which the signal from the transducer is monitored and balanced to bring this signal very close to zero volts.

3.8.4 Autonomous Operation

A mode, which is not used by MPD but is available, allows for programming of all the settings and a time at which the recorder will automatically go into a 'waiting-to-record' mode. It would provide the excitation to the transducers and then allow a pre-set time before balancing the signal, as described above, then proceed into a record mode, waiting for the appropriate trigger signal. After another programmable time, if no trigger signal was received, it would take itself out of record mode.

3.8.5 LED Indicators

Each unit has four Light Emitting Diode (LED) indicators. These indicate the state of the recorder. They inform users of the presence of internal & external power and to a limited extent the mode that the unit is in.

3.8.6 Packaging

The DIGISTAR recorders are built with an aluminium casing that can slide into an adjacent unit. In this way any number of units can be joined. MPD had aluminium boxes made to accommodate and protect 5 units. This was a compromise between a useable number of DIGISTAR units and the weight of the units so joined. The boxes provide a convenient way to transport the units and provide additional protection with foam packaging. The lid protects the connections from the test environment. Conveniently the boxes provide space on either side of the units for cables and connectors. See Figure 1.

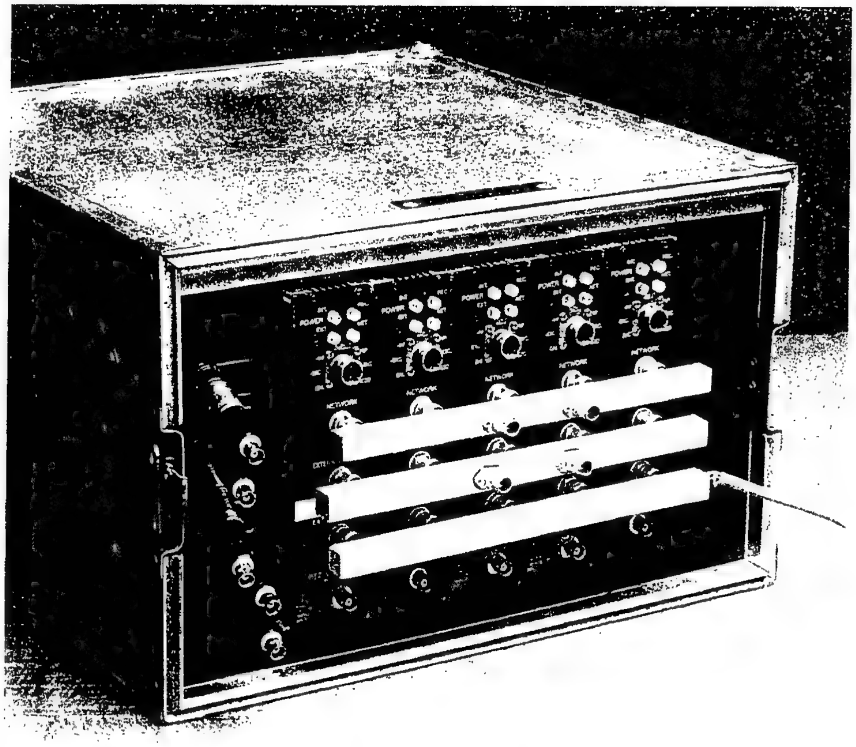

Figure 1: Current configuration of 5 DIGISTAR recorders housed in an aluminium box. Consisting of network, trigger and power connection bars, the 6 pin cannon and BNC transducer connections above and below the bars respectively, and each units power connections on the left.

4. Problems Encountered

The introduction of the DIGISTARS necessitated a radical rethink of instrumentation methods. The instrumentation capability prior to the DIGISTARS had evolved incrementally. The adaption of the existing instrumentation and the DIGISTARS so as all the instrumentation meshed took time and a number of iterations. During this time some problems with the DIGISTARS became evident. This was mainly due to insufficient detail supplied in the manuals to obtain a complete understanding of the circuitry and software. Support from the manufacturers had ceased soon after the purchase of the DIGISTARS. With insufficient documentation and no support, maintenance of the units has been laborious and somewhat limited.

4.1 Internal Batteries

The primary problem encountered with the DIGISTAR units as purchased involved the internal NiCad batteries. The batteries generated several concerns. The batteries were hard-wired into the circuitry and the DIGISTAR units include a charging circuit.

Most times the units were used, they would be placed in a charge cycle to charge the internal batteries from the external power source before any attempt to use them to record data. However there was no means of determining the state of charge of the batteries. Unfortunately NiCad batteries suffer from a 'memory' effect if they are not fully discharged before being recharged so the time available for recording is reduced with continual charging.

When the battery charge dropped below a certain level the units would not respond over the network and without knowing the cause many other options for non-response were investigated. If left for a long time the internal batteries would discharge to a very low state and the units could not be recovered without opening the units, disconnecting the batteries and charging the batteries from an external supply direct to the batteries. This entailed de-soldering the leads from the batteries to the printed circuit board. A practice not advisable to do regularly.

To avoid any discharge of the internal batteries the units were stored with a connection to an external 12 Volt supply. On some occasions the units were packed and transported for use in the field at some distance from the laboratory. For some experiments this transport by necessity occurred a considerable time before the experiment. When personnel arrived at the experimental site the units would not function due to insufficient internal power.

4.2 Transducer Connections

When the DIGISTARS were first purchased a combination of instrumentation was used. The normal set of transducers used for transient measurement in MPD where of two basic types: Piezo-electric which used a coaxial connection; and Piezo-resistive which used a 'Cannon' 6 pin connection. The DIGISTAR units used the one 'Lemo' connector for both types of transducer. To enable a convenient means of rapidly changing transducer types a small breakout box was made for each unit. This breakout box was a short lead with a 'Lemo' connector on one end and a diecast box with a coaxial and 6 pin connector, Figure 2. This achieved the aim but added two connections that could cause problems and a diecast box that at times could cause ground connection problems.

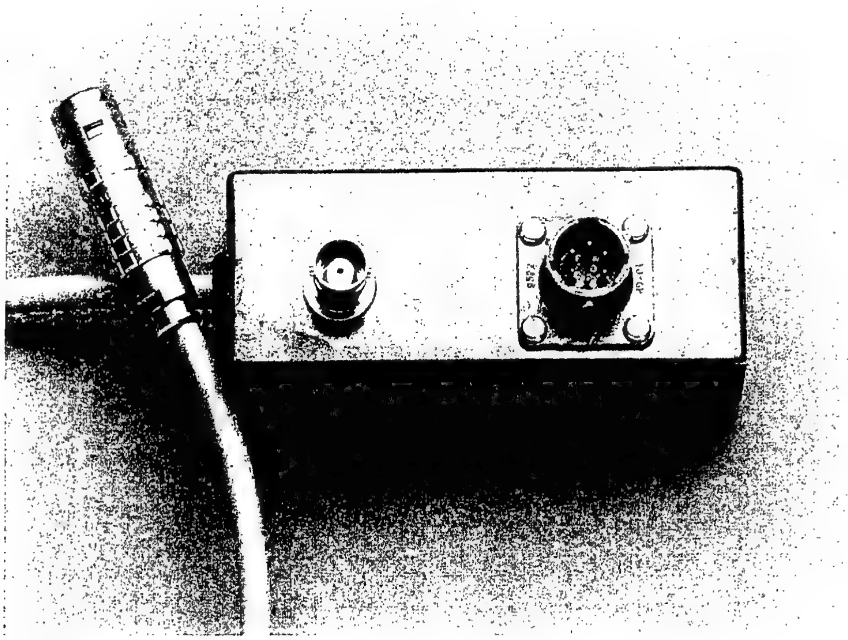

Figure 2 . Break out box

4.3 Components

Since acquiring the DIGISTARS several units have failed to operate correctly. This has been primarily due to circuit board mounted fuses blowing. Other reasons have been due to damaged surface mounted resistors located near the power supply circuitry, transistors located within the networking circuitry and dry solder joints developing.

4.4 Computers

The DIGISTAR units were purchased when 80386 microprocessor- based PCs were on the market. MPD purchased two Compaq 386 portable computers with Windows 3.1 installed. This system operated without any problems but soon become outdated. When more modern computers were purchased it was difficult to find a computer capable of operating the DIGISTARS. Compatibility problems were encountered. Several types of 486 based computers failed to operate the DIGISTARS correctly. Some later computers (Pentiums) could not communicate with the DIGISTARS without causing communication errors.

In order to "prove" compatibility with DIGISTARS units, it was necessary to connect 20 DIGISTAR units using a line driver to the computer and configuring the computer to extract 4 million samples from each unit. If each unit's data was extracted without causing an error the computer was proven to be compatible. Several Pentium based computers were tested using this procedure without success. The common fault being that communication errors occurred during extraction after several units successfully had data extracted, which resulted in the loss of communication to all units.

A computer which passed the test is a Celeron- based 550 Mhz notebook with Windows 98 installed. The notebook requires initialising prior to use. DIGISTAR units on the network are mapped onto a matrix within the software. To establish communication and identify units on the matrix it is necessary to have one unit only selected in the matrix, apply a 'Setup' then a 'Reset'. This procedure will enable the unit to be identified in the matrix. The DIGISTAR software has a 'Scan' button which when selected scans the units on the matrix and identifies them as being on the network.

Prior to any attempt to communicate, it is necessary to perform a pulse factor calibration. Pulse factors are used by the software so that the duration of a pulse sent to the DIGISTAR recorders is always the same no matter what computer is used. This measurement needs to be accurate. A procedure for the pulse factor calibration is included in the proprietary software.

5. Modifications

5.1 Batteries Disconnection

When internal batteries where replaced they were first disconnected from the internal circuitry. When this was done a connector was installed between the batteries and the DIGISTAR circuitry to avoid repeatedly soldering/desoldering on the circuit board. When power was reconnected a simple process of programming the recorders and resetting them put the DIGISTARS back into their normal mode of operation.

To avoid the uncertainty with the level of charge of the batteries they were disconnected when the units were not in use. A number of connection prototypes were evaluated. The final version entailed a cable inserted though the back of each unit, with connections to the batteries and circuitry, fitted with a three-pin 'Cannon' connector as depicted in Figure 3. This allows the internal battery to be connected to the circuitry by inserting the mating three-pin connector or charging the internal batteries from an external source without using the internal DIGISTAR circuitry. It also provides a BNC coaxial connector in the back of the mating three-pin 'Cannon' connector that is connected across the internal batteries. This allows the voltage on the internal batteries to be monitored while they are in use.

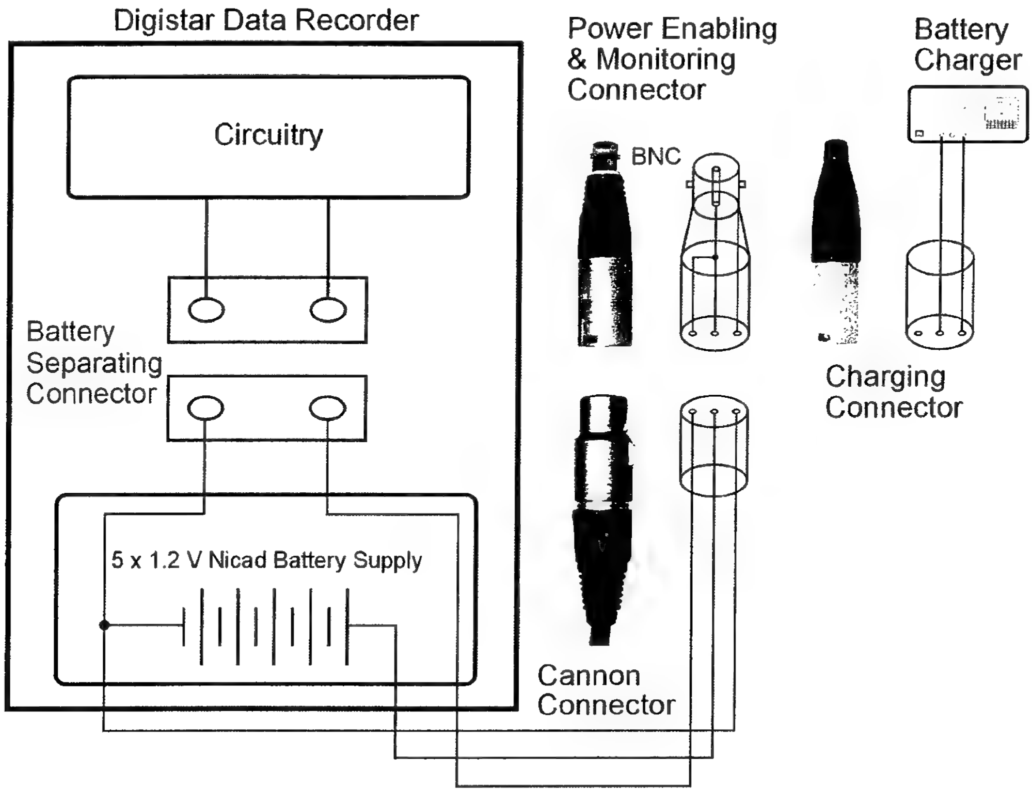

Figure 3. Internal Battery Power Supply Connection.

5.2 Internal Batteries

Nickel metal hydride and sealed lead acid batteries were tested as a replacement for the internal NiCad batteries to alleviate the memory effect characteristic of NiCad batteries. However the lead acid batteries caused the DIGISTARS to malfunction due to incompatible input impedance with the charging circuitry. Although Nickel metal hydride batteries are compatible, their operating life is much shorter than that of NiCad batteries. NiCad batteries continue to be used. The largest capacity batteries available have been installed and a battery management system to maintain conditioned batteries has been instituted. When the DIGISTAR units were purchased they contained 2.2Ah NiCad batteries. They have since been replaced with 3.0Ah batteries.

5.3 Charging Circuits

The internal NiCad batteries were now accessible through the connections described in Section 5.1 for monitoring and charging. There are particular charging techniques for NiCad batteries which can prolong their life and maintain their nominal power capacity. A battery charger designed for NiCad batteries which can cycle the battery power and re-

charge them at the correct currents was purchased and fitted with mating connectors to those described in section 5.1. This charger also provides a report on the capacity of the batteries. This is used to determine when batteries require replacement. See Figure 4.

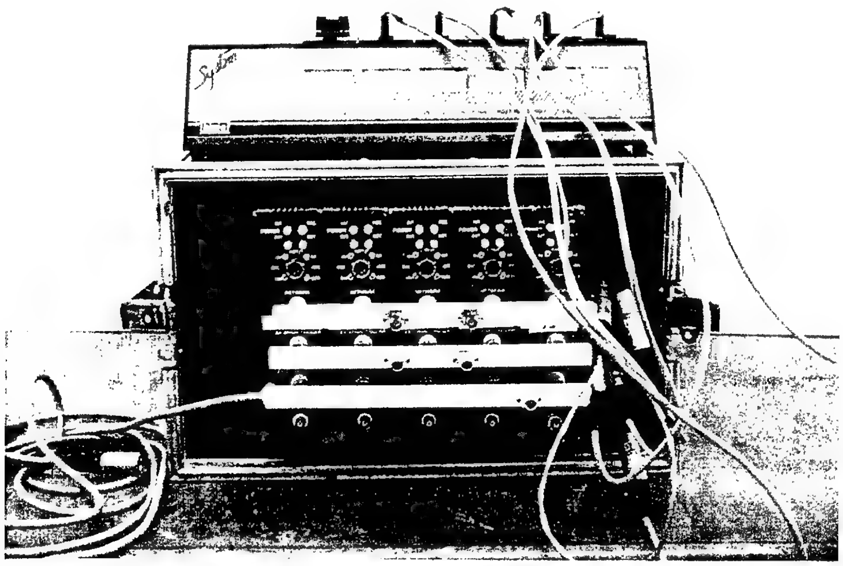

Figure 4: The System 90 battery charging system.

5.4 Transducer Connections

MPD use two transducer types almost exclusively when measuring transient signals as described in this paper. The two types use the two connections described in Section 4.2. The 'Lemo' transducer connector on the front panel has been replaced with two connectors: the Cannon 6 pin connector and the BNC coaxial connector. This alleviated the need for the breakout box and eliminated problems associated with the extra cabling and connections.

5.5 Network, Trigger, and Power Connections

The connections on the front panel for the Network, Trigger and External Power are BNC coaxial connectors. These are convenient, robust connectors. When many are located in a small area and connections are required between them the space is quite restricted. BNC T pieces of various shapes were used in an effort to provide the connections and still provide the capability of connection and disconnection. None was found suitable. A purpose built connector was made for the five units in each of the boxes using panel mounted BNC connectors and a piece of square electrical ducting. Five female connectors were placed on

one side of the ducting, with the appropriate spacing to fit the units, and two male connectors on the other side to allow boxes of DIGISTARS to be 'daisy-chained' together. This was appropriate for the Network and Trigger connections. See Figure 1.

The external power connections were accommodated in a similar manner but instead of having the two male connections a lead from one end of the ducting fitted with a rugged cannon connector was used. This mates with those on power supplies and batteries as described in Section 6.1.

6. Current Methodology

6.1 External Power

The external power required is 12 Volts DC. MPD have numerous power supplies made for this purpose and whenever 240 Volts AC power is available close to where the DIGISTAR units are being used it is preferable to use these power supplies.

When 240 Volt power is not available, MPD have a number of 12 Volt, 24 Ah lead acid batteries fitted with appropriate connectors which can quickly be connected to the external power connections of the DIGISTARS. The 12 Volt batteries can also be charged using the above-mentioned power supplies. The power supplies have connectors to suit the external power of the DIGISTARS and to charge the 12 Volt batteries.

At the laboratory a battery charger which permanently trickle chargers the batteries is used. This charger can accommodate 12 batteries and monitor each individually and "quick charge" those which are not fully charged and then trickle charge them for as long as they are connected. In this way MPD have a large number of batteries fully charged ready for use. See Figure 5.

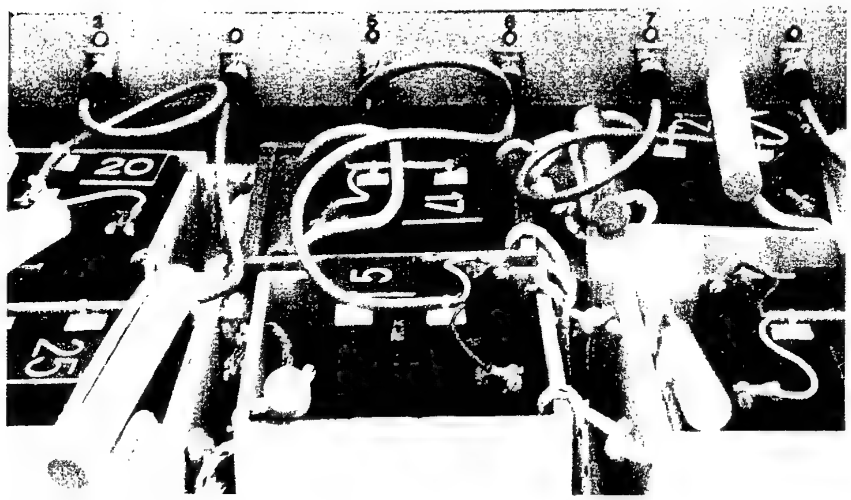

Figure 5: Sealed Lead acid battery charging system. Supports up to 12 batteries.

6.2 Internal Battery Management

The internal batteries are routinely monitored and cycled using the charger described in Section 5.3. Before any required task the batteries are monitored, recharged, or replaced as necessary.

The internal charger is used during experiments when a DIGISTAR unit shows signs of low internal battery voltage. Indications include communication problems, errors during data extractions, errors while programming the DIGISTAR units or units not responding to a 'Scan'.

When the DIGISTARS are not being used and the internal batteries disconnected from any circuitry the batteries last for many months and many uses before any signs of deterioration are observed.

6.3 Calibration

The DIGISTARS are regularly calibrated by applying known voltages from NATA certified secondary standards and acquiring the signal. Analysis of the signals over the life of the DIGISTARS shows the DIGISTARS have maintained accuracies at better than 0.5% of full scale.

7. Discussion

The designers and manufacturer of the DIGISTAR acquisition systems, ATS Aerospace Inc, discontinued manufacture and support for the units in the mid 1990s. The remaining parts and available documentation were purchased by DSTO. Although a comprehensive knowledge of the design has not been possible it has enabled the repair of some units when they have malfunctioned.

The modifications and methodologies developed have enabled a large number of experiments to be conducted with many channels of data being acquired with minimal staff effort. The principal benefit of the DIGISTAR units is the ability to place the units in close proximity to detonating explosives as this obviates the need for running long cables from transducers to recording instrumentation. The other benefit over conventional instrumentation is the ability to connect to several transducer types without additional amplifiers.

Overcoming the battery management issue has meant the DIGISTARS have been a reliable, versatile and labour saving capability and have become the main transient data acquisition system for MPD.

8. Conclusion

The DIGISTAR units were purchased when a significant increase in MPD's capability to measure transient responses was required. The DIGISTAR units provided a challenge with respect to the development of new instrumentation methodologies and the inherent problems associated with their battery power sources. These challenges have been met and new methodologies and management systems developed.

The DIGISTARS are now a very reliable, versatile and accurate acquisition system for transient responses. The quantity and complexity of experiments successfully conducted utilising the DIGISTARS would not have been possible with conventional instrumentation and the available personnel resources.

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19. ABSTRACT

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